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Reconstructing Paleo-Sulfate Methane Transition Zones (SMTZs) in the Japan Trench

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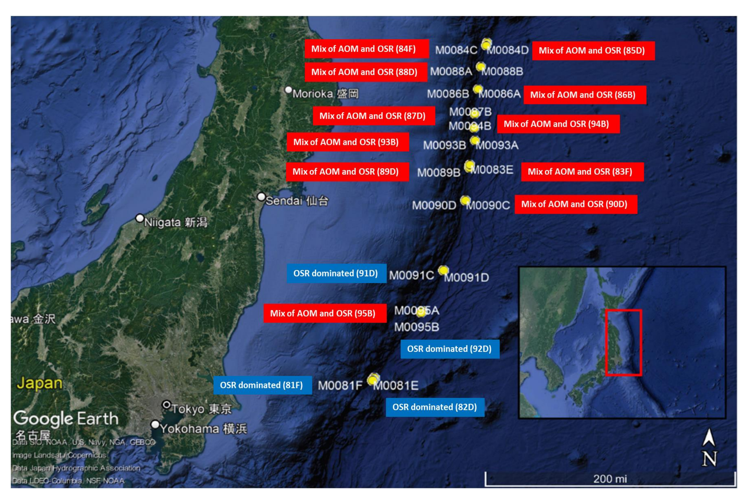
Abstract

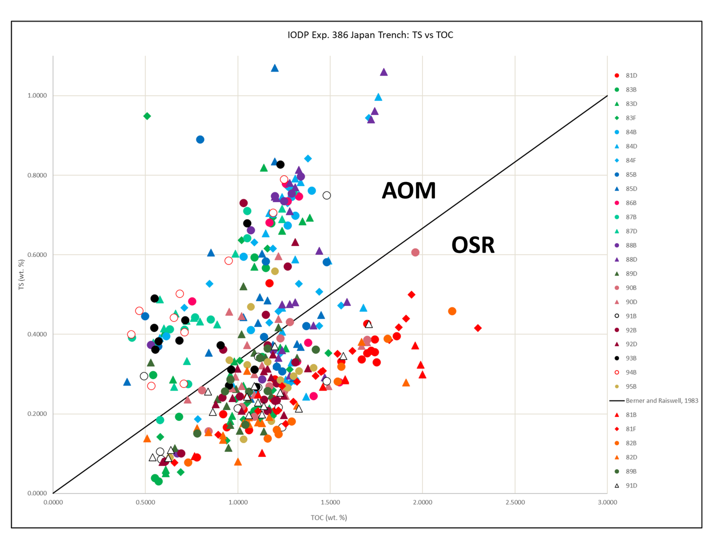
In subduction zone trenches, the movement of pore fluids and/or their expulsion, as well as slope failure, are likely to occur during earthquake ruptures and leave evidence in the sedimentary record. In the Japan Trench, slope failures are well correlated to historic subduction zone earthquakes. During recent IODP Expedition 386, 40 m long piston cores were recovered from 15 sites located in basins along the Japan Trench. These cores provide a new and potentially longer-term record of paleoseismic activity. With these cores, we aim to reconstruct the positions of paleo-SMTZs throughout the sediment layers by analyzing total sulfur (TS), $\delta^{34}S_{TS}$, total organic carbon (TOC), and $\delta^{13}C_{TOC}$. These measurements will help us understand the response of paleo-SMTZs to sedimentation and fluid advection induced by past subduction zone earthquakes. Initial shipboard measurements of TS and TOC suggest that organoclastic sulfate reduction (OSR) and anaerobic oxidation of methane (AOM) are the primary processes influencing the position of the SMTZ through time. We present high-resolution TS records for 3 of the 15 sites, located in the northern, middle, and southern parts of the Japan Trench, respectively. In one of these records, consistently low TS suggests OSR dominance with no overprinting by the SMTZ. In the other 2 records, elevated sulfur corresponds with the modern SMTZ and suggests paleo-SMTZ positions. Downcore patterns of TOC and TS are well correlated, suggesting OSR is the primary control on TS content. However, the presence of methane in these cores, and elevated sulfur relative to TOC, suggest AOM also influences TS content. Pending measurements of $\delta^{34}S_{TS}$ in these same records will reveal the relative influence of AOM and OSR and confirm past SMTZ positions. We will integrate our new findings with known earthquake-induced sedimentary deposits and pore fluid geochemistry of these records to determine possible drivers for SMTZ changes through time. These results, obtained from all 15 sites, will ultimately reveal spatial patterns that can be correlated with past megathrust ruptures in the Japan Trench.

Tectonic Setting

- Japan Trench is a plate boundary where Pacific Plate subducts beneath Okhotsk Plate at 8.0 to 8.6 cm/yr (1)
- Relatively recent seismic events correlated with historic records as a starting point to gather data about responses during, and proxies for, past megathrust earthquakes
- Some events preserved as slope failure deposits in short cores (10 m) previously collected in Japan Trench and are likely present in longer (40 m) records collected during Exp. 386 (1, 3, 9)
- Sedimentary deposit associated with 2011 earthquake recovered in cores (1, 2)
- Discovery of sediment deposits caused by last three major earthquakes during past 1500 years: 2011 Tohoku-Oki, 1454 Kyotoku, and AD 869 Jogan earthquakes (1, 2, 3, 4)
- Event deposits: match historic records from ash chronology, deposited instantaneously (remobilized clays to turbidites) (4, 5, 6, 7)
- Establish age constraints and earthquake-linked event deposits from uppermost 10 m of seafloor as starting point for 40 m records
- Throughout Japan Trench, cores document modern SMTZs at variable depths and many sites indicate non-steady state conditions
- Hint at dynamic SMTZ system since 2011 Tohoku-Oki earthquake and a potentially diagnostic response expected for previous megathrust events



Map of IODP Exp. 386 piston core locations within the Japan Trench. Bathymetry from Google Earth. Seafloor depths at the sites range between ~7000-8225 mbsf (8).

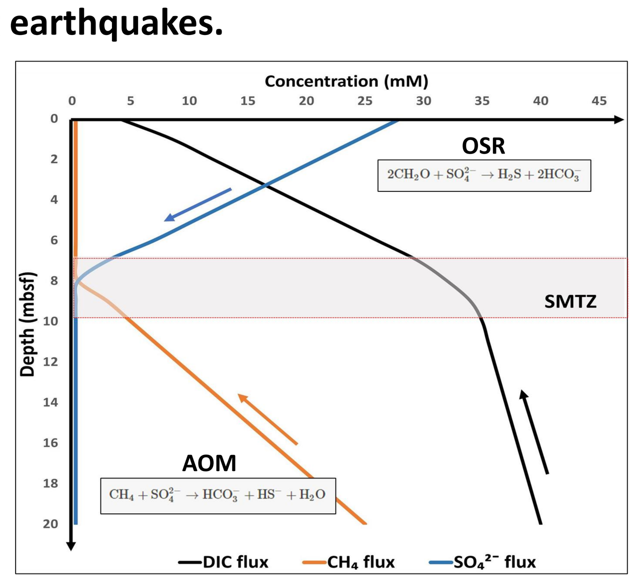


Shipboard measured TS and TOC cross-plot for each core taken at the 15 sites. Most sites show elevated TS zones consistent with AOM-influenced pyritization.

Research Approach

Hypothesis: A record of megathrust earthquakes in these cores may be recorded in the diagenetic minerals formed from subseafloor fluid mobilization events during earthquakes.

- Reconstruct paleo-SMTZ (sulfate-methane transition zone) positions throughout records by analyzing sediment samples from Exp. 386 cores
- Measured bulk sediment TS in all cores taken along Japan Trench
- Measured bulk sediment $\delta^{34}S_{TS}$ in three cores: 81F, 83F, and 84F
- Examples of an organoclastic sulfate reduction (OSR) dominated record (Site 81F) and anaerobic oxidation of methane (AOM) influenced records (Sites 83F and 84F)
- Sample measurement density was 1 sample/meter for TS using the Elementar CHNS elemental analyzer at UNH
- Isotope measurement at the UC Berkely Center for Stable Isotope Biogeochemistry
- Also utilizing sulfate, methane, and TOC shipboard measurements



SMTZ diagram showing concentration profiles for CH_4, SO_4^{2-}, and DIC (10).

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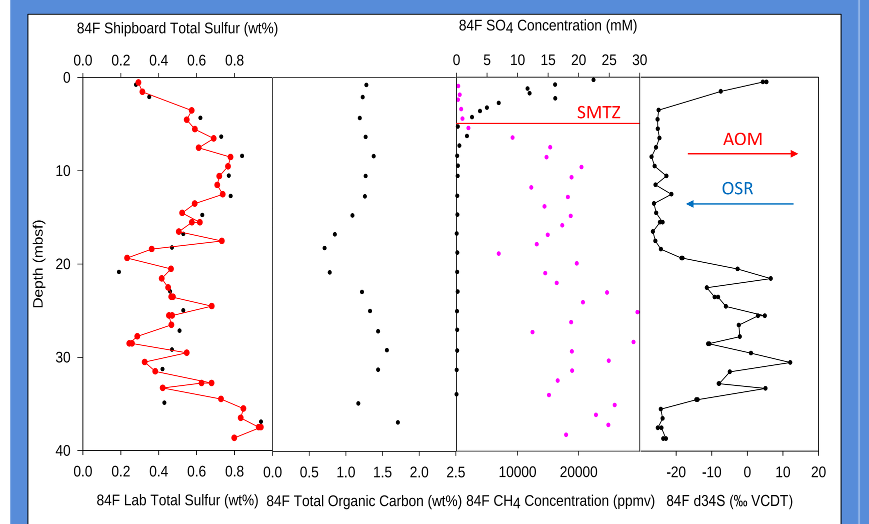
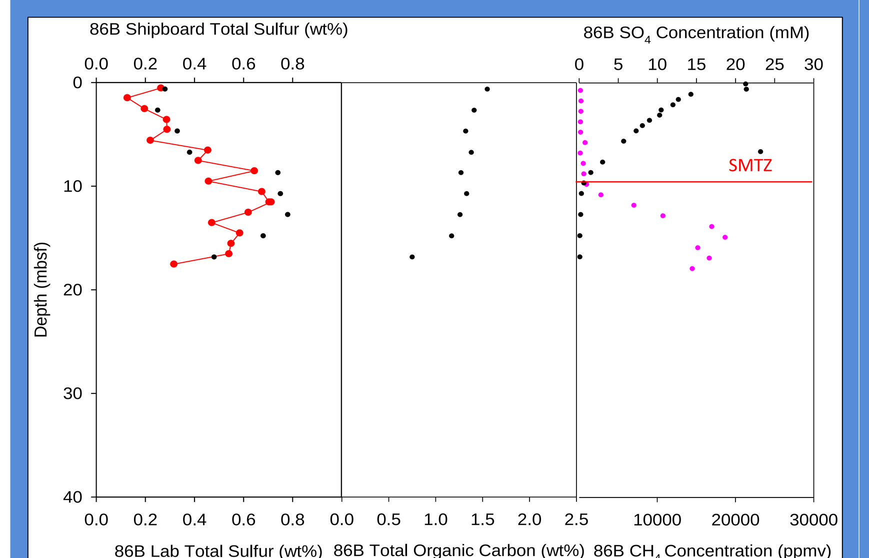
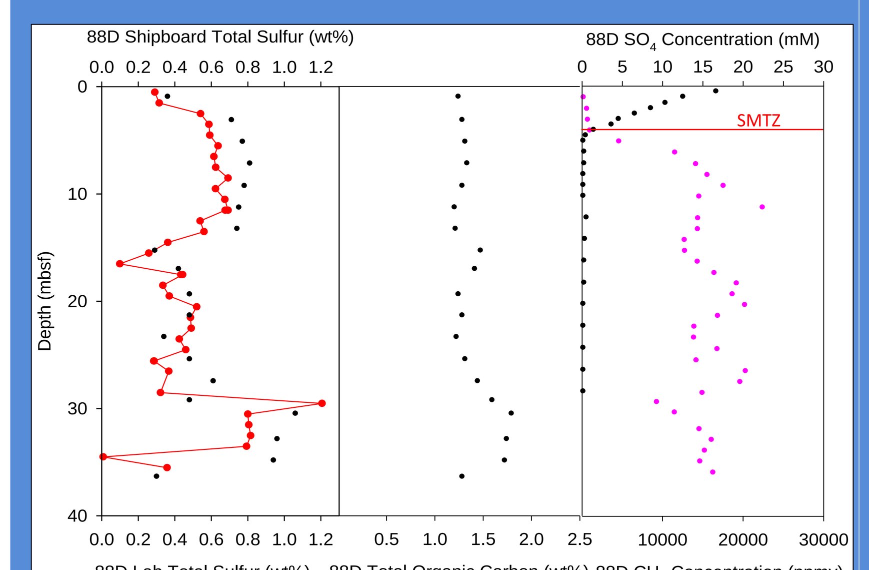
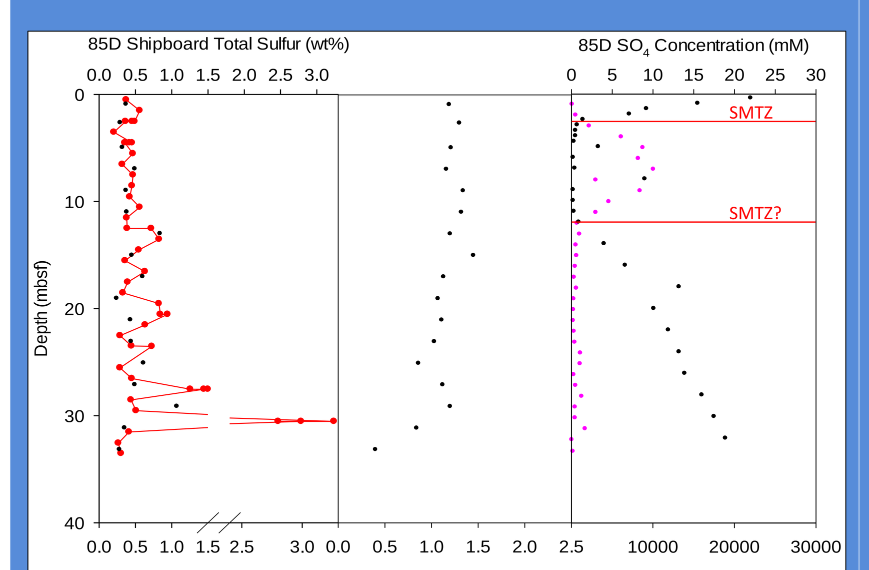
Results and Discussion

Northern Japan Trench



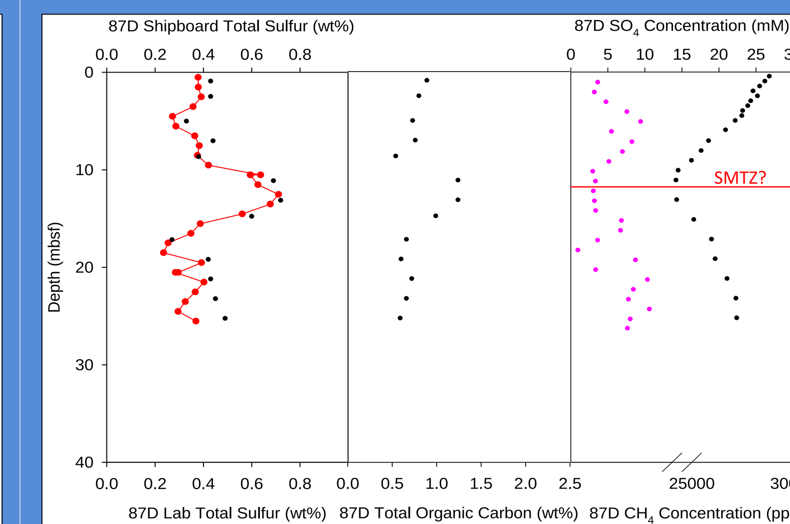


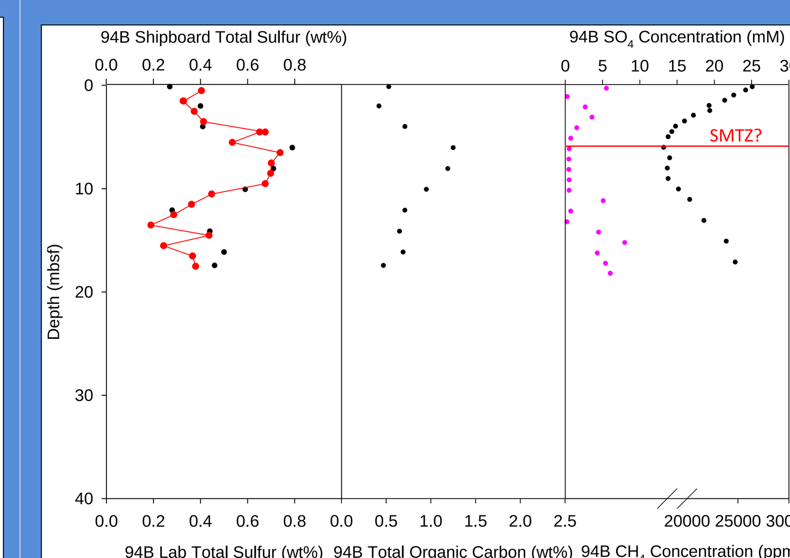


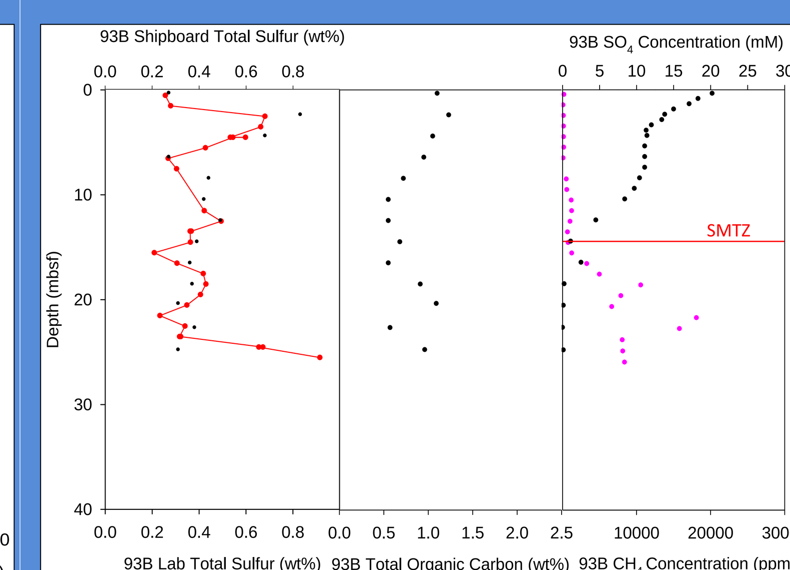


- 84F and 88D have multiple sulfur peaks
- 85D has mostly background sulfur levels with two big peaks
- 86B shows one broader peak, possibly indicating a slowly moving SMTZ
- 85D sulfate and methane show two possible SMTZs
- 85D TS has two significantly high peaks: 1.3 wt% and 3 wt%, both towards the bottom half of the core
- Duplicates of these samples indicate they are valid results
- 84F sulfur isotopes indicate predominantly AOM enrichment

Central/northern Japan Trench

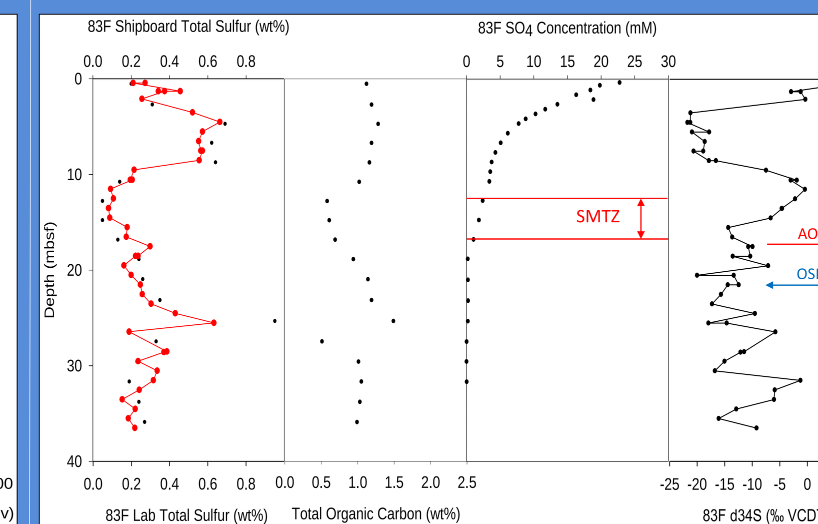


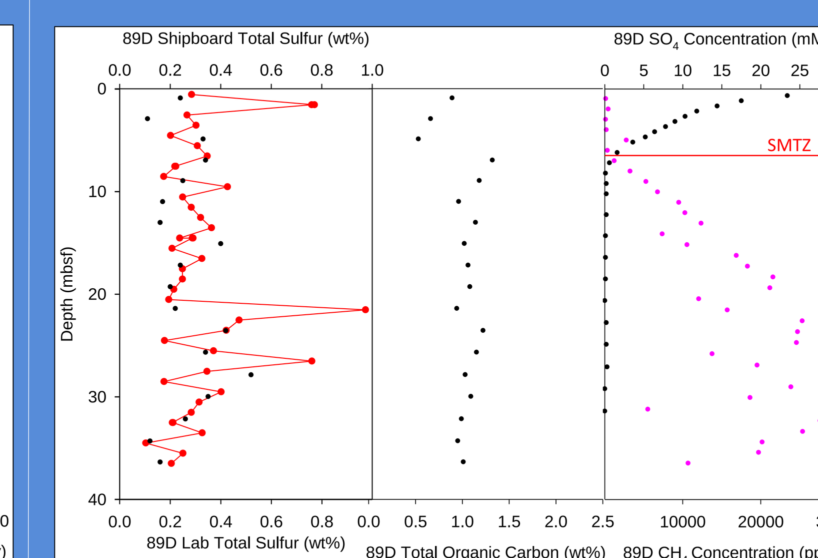


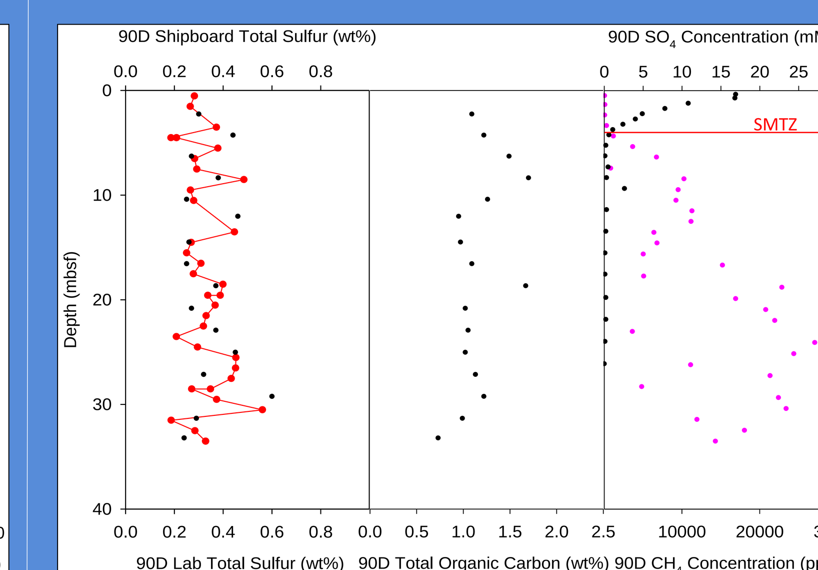


- 87D and 94B show broad peaks of TS, possible slower movement of SMTZ
- 93B demonstrates multiple sulfur peaks, some sharp and some broad, which might reflect alternating faster and slower movement of SMTZ in this location
- Hard to distinguish modern SMTZ at sites 94B and 87D as measured sulfate and methane concentrations do not reach zero
- TS:TOC crossplot indicates that sulfur was created by both AOM and OSR
- No isotopes from this region yet

Central Japan Trench

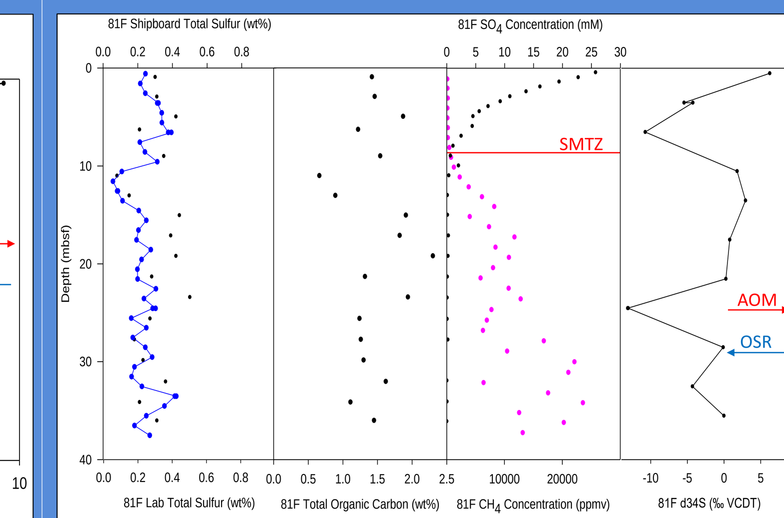


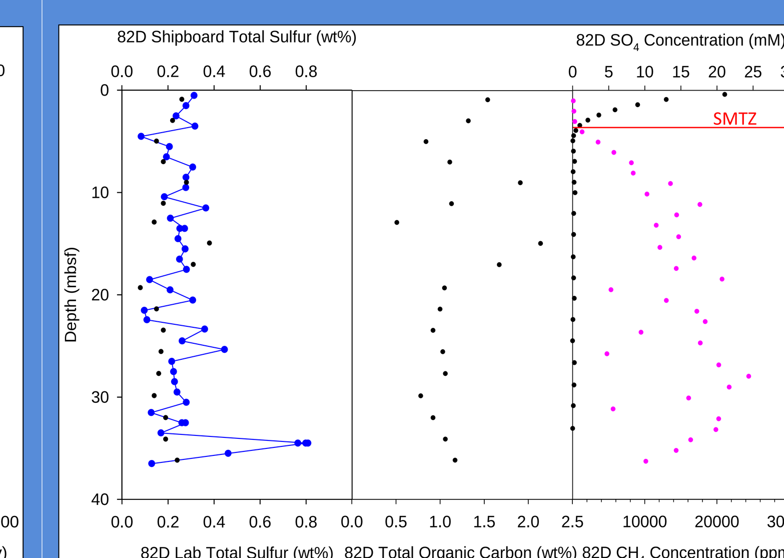


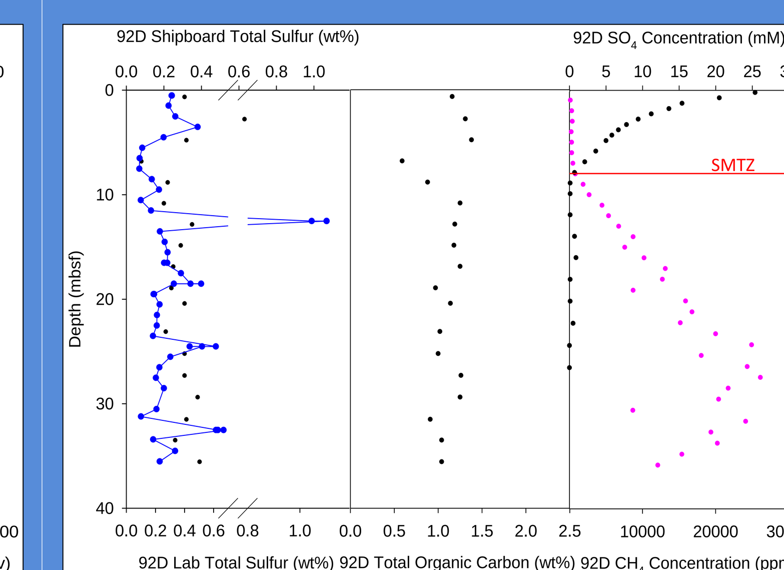


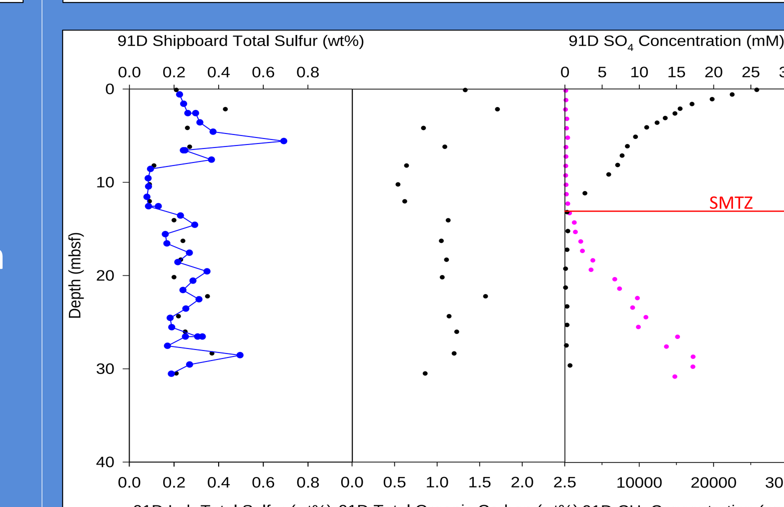
- 83F shows multiple peaks of sulfur within central Japan Trench
- No methane was measured at this hole, so it is hard to place the depth of SMTZ
- TS:TOC crossplot shows influence from both AOM and OSR
- Isotopes also indicate that sulfur originates from both AOM and OSR
- 90D shows mostly background levels of sulfur with minimal peaks
- TS:TOC crossplot shows a mix of AOM and OSR influence

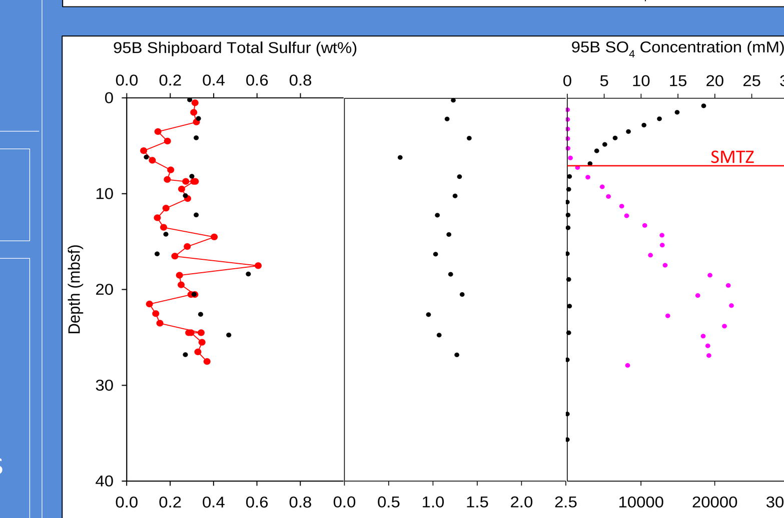
Southern Japan Trench











- Mostly OSR-dominated (blue graphs), except for 95B, which has a mix of AOM and OSR
- Most sites show low TS at background levels with a few small peaks
- 81F isotopes indicate that the TS is a mix of OSR and AOM

Conclusions

- TS:TOC crossplot indicates that southern locations in Japan Trench are more OSR-dominated
- Central and northern locations are influenced by AOM and OSR based on crossplot and isotope measurements
- Some southern Japan Trench sites show non-variable background TS with no peaks while others show mostly background TS levels but one or two sharp peaks
- Central Japan Trench demonstrates two trends: multiple TS peaks and non-variable background TS with no peaks
- Central/northern and northern Japan Trench shows multiple sharp TS peaks and broad TS peaks
- Sites with sulfur isotope measurements (83F and 84F) indicate multiple paleo-SMTZ locations

Future Work

- Need to conduct more isotope measurements on the remainder of the sites to determine the origins of the sulfur
- Also need increase sampling density for 81F isotopes as the current plot does not show the full picture yet
- Isotope measurements will inform our future research efforts, such as where to sample for trace metals to determine which paleo-SMTZs were emergent at the seafloor
- Integrate our paleo-SMTZ reconstructions with Japan Trench sedimentology and stratigraphy to potentially reveal the influence of earthquakes on these records